



## Evaluating Imaging Follow-Up Strategies and Costs of Unruptured Intracranial Aneurysms Treated with Endovascular Techniques: A Survey of Academic Neurovascular Centers in the United States

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■ **BACKGROUND:** Unruptured intracranial aneurysms (UIAs) are being detected and treated with endovascular techniques at an increasing rate, with little evidence on the optimal imaging follow-up protocol. We performed a survey of academic neurovascular centers in the United States to assess imaging follow-up strategies and costs after endovascular treatment of UIAs.

■ **METHODS:** An online survey on 5-year follow-up strategies of UIAs treated with endovascular techniques was distributed to neurovascular directors of 101 academic neurovascular centers using the American Association of Neurological Surgeons/Congress of Neurological Surgeons Joint Cerebrovascular Section database. An online healthcare marketplace, NewChoiceHealth, was used to calculate costs.

■ **RESULTS:** Of 33 (32.7%) institutions that responded to the survey, 26 (25.7%) provided data suitable for analysis. Nine (34.6%), 10 (38.5%), 4 (15.4%), and 3 (11.5%) centers were located in the northeastern, southern, midwestern, and western regions of the United States. Total costs of 5-year follow-up imaging after primary coil embolization and stent-assisted coiling procedures were \$3391–\$32,882. Costs for aneurysms treated with flow diversion were \$2788–\$46,670. Eighteen (69.2%) institutions performed cerebral angiography at 6-month follow-up after coil embolization and stent-assisted coiling, and 19 (73.1%) institutions performed cerebral angiography 6 months after flow diversion. Of institutions, 20% affirmed that they

maintained an identical imaging follow-up regimen after treatment of ruptured aneurysms.

■ **CONCLUSIONS:** There is significant heterogeneity in imaging follow-up strategies and their associated costs. Stratification of patients by risk of recanalization and corresponding adjustment of follow-up imaging may be 1 strategy to limit unnecessary imaging and control costs.

### INTRODUCTION

Detection of unruptured intracranial aneurysms (UIAs) has increased dramatically over the past several decades as a result of increased use of computed tomography angiography (CTA) and magnetic resonance angiography (MRA).<sup>1,2</sup> Worldwide, aneurysms are present in 3.2% of adults with an average age of 50 years at presentation (95% confidence interval, 1.9%–5.2%).<sup>3</sup> However, only a very small percentage of UIAs ever rupture.<sup>3</sup> Nevertheless, the number of UIAs treated, with endovascular techniques in particular, is increasing.<sup>4</sup> During 1998–2003, the percentage of endovascularly treated UIAs increased nearly 4-fold.<sup>3</sup> Although complete occlusion of the aneurysm is the primary intention with endovascular techniques, such as primary coil embolization, stent-assisted coiling, and flow diversion,<sup>5</sup> some of these aneurysms have the propensity to recanalize or fail to occlude after the initial treatment. The precise risk associated with recanalization is unknown; however, data from previously ruptured aneurysms indicate that the extent of aneurysm recanalization is a key predictor for the risk of

#### Key words

- Costs
- Endovascular treatment
- Follow-up imaging
- Unruptured intracranial aneurysms

#### Abbreviations and Acronyms

**CTA:** Computed tomography angiography  
**DSA:** Digital subtraction angiography  
**MRA:** Magnetic resonance angiography  
**UIA:** Unruptured intracranial aneurysm

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rupture.<sup>6</sup> To ensure complete occlusion of the aneurysm over time, follow-up imaging is essential. Studies demonstrated that both MRA and CTA offer a level of sensitivity and specificity of detection of recanalization comparable to digital subtraction angiography (DSA).<sup>7-10</sup> The ideal strategy for imaging follow-up, such as timing and imaging modality, however, has not been identified. We performed a survey of academic neurovascular centers in the United States on imaging follow-up strategies of endovascularly treated UIAs and calculated the cost associated with each strategy.

## MATERIALS AND METHODS

### Online Survey

Institutional review board approval was waived for the purposes of this study. Using the online cloud-based software, Survey Monkey,<sup>11</sup> a survey (Tables 1 and 2) on 5-year follow-up strategies of UIAs treated with endovascular techniques was distributed to neurovascular directors of 101 academic neurovascular centers using the American Association of Neurological Surgeons/Congress of Neurological Surgeons Joint Cerebrovascular Section database in March 2016. After weekly reminder e-mails were sent to the same audience, the survey was closed after a total duration of 2 weeks.

### Cost Estimation

An online healthcare marketplace, NewChoiceHealth,<sup>12</sup> was used to calculate the cost of each imaging follow-up strategy, as determined by the median reimbursement paid to hospitals by insurance providers, including Medicare and Medicaid, within a given ZIP code. An average inflation rate of 3% was applied to estimate the price of imaging in its respective time frame.<sup>13</sup>

### Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows version 21.0 (IBM Corporation, Armonk, New York, USA). Costs of individual regions were compared using analysis of variance. Statistical significance was defined as  $P < 0.05$ .

## RESULTS

Of 33 (32.7%) institutions that replied to the survey, 26 (25.7%) provided a complete response that was incorporated into the analysis. Responses were divided across all regions in the United States, with 9 (34.6%), 10 (38.5%), 4 (15.4%), and 3 (11.5%) centers located in the Northeast, South, Midwest, and West, respectively. All respondents (100%) identified that their follow-up imaging protocols were the same for aneurysms treated with primary coil embolization and stent-assisted coiling. The imaging follow-up strategies for coiling, stent-assisted coiling, and flow diversion were reported to be identical by 17 (65.3%) of the institutions. All 26 institutions adopted a different imaging follow-up strategy. Of institutions, 20% affirmed that they maintain an identical imaging follow-up regimen after treatment of ruptured aneurysms. The median price for DSA ranged from \$4039 (Chicago, Illinois) to \$13,820 (Phoenix, Arizona). The median price for MRA ranged from \$1035 (Los Angeles, California) to \$1381 (Philadelphia, Pennsylvania).

### Cost Estimation

Total costs of follow-up imaging in the first 5 years adjusted for inflation after primary coil embolization and stent-assisted coiling were \$3391–\$32,882 (Figure 1). For aneurysms treated with flow diversion, these costs were \$2788–\$46,670. Average costs for follow-up imaging for patients having undergone primary coil embolization and stent-assisted coiling in the Northeast, South, Midwest, and West were \$16,880, \$16,146, \$13,329, and \$24,660 ( $P = 0.388$ ) (Figure 2). Following flow diversion, the average costs were \$16,973, \$14,642, \$18,027, and \$29,256 in the same regions ( $P = 0.114$ ).

### Preferred Imaging Modalities

Immediately following stent-assisted coiling and coil embolization, 5 (19.2%) of the institutions performed 3-month follow-up imaging (4 MRA, 1 DSA), 20 (80.8%) institutions performed 6-month follow-up imaging (17 DSA, 3 MRA), and 1 institution performed 1-year follow-up imaging (DSA). After flow diversion treatment, 7 (26.9%) institutions performed 3-month follow-up imaging (4 MRA, 2 DSA, 1 CTA), and 19 institutions performed 6-month follow-up imaging (17 DSA, 2 MRA). Eighteen (69.2%) of the institutions reported that they performed DSA 6 months after coiling and stent-assisted coiling compared with 19 (73.1%) that reported performing DSA after flow diversion. Sixteen institutions (61.5%) reported using both DSA and MRA after stent-assisted coiling and coil embolization; 17 (65.3%) reported using these combined imaging modalities after flow diversion. A median of 4 (range, 3–6) imaging studies were performed across the 5-year follow-up period, following primarily coil embolization and stent-assisted coiling. Similarly, a median of 4 (range, 2–6) imaging studies were performed after flow diverter placement within this time interval. Only 1 (3.8%) institution reported the use of CTA (after flow diversion).

## DISCUSSION

Imaging follow-up strategies and associated costs of endovascularly treated UIAs vary widely throughout the United States. Imaging follow-up for aneurysms treated with primary coiling or stent-assisted coiling at 1 institution is almost 10 times more expensive than at another institution. For flow diversion, there is a >16-fold difference in costs between institutions. A standardized protocol that identifies the appropriate imaging modality and the time point at which it should be obtained has not been developed. A stratification system that incorporates risk factors for both recanalization and rerupture is needed. UIAs are being detected in a growing number of patients.<sup>3</sup> Indications for treatment of UIAs are subject to significant debate, given the low rates of rupture of smaller aneurysms; the increased risk of rupture associated with personal or family history of subarachnoid hemorrhage; and the compounding anatomic, modifiable, and familial risk factors involved.<sup>2,14</sup> This situation is complicated further by significant patient anxiety and uncertainty on diagnosis, skewing physicians' decisions toward either intervention or conservative management.<sup>15</sup>

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